USING COMPUTER GRAPHICS AND COMPUTER AIDED DESIGN METHODS INTO THE CONCEPTION OF THE BOLTED CONNECTIONS

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ABSTRACT

As a result of the application of the tools provided by the digital computer and interactive computer graphics, the reality of modern mechanical engineering design in the current industrial environment is changing. At the same time, customer expectations for the quality and durability of products are continuously increasing and the constraints of cost and lead-time are becoming more and more compelling.

This situation poses new challenges in the product-development process and introducing, also, new demands in the preparing process of tomorrow's engineers and scientists, in order to a proper integration in the engineering curricula of the computer aided design, which eliminates the need for costly changes, unnecessary delays or unsatisfactory design releases.

Along these lines, the objective of the paper is to present some of our experimented ways of integrating the CAD basics concepts with the use of a specifically design and analysis software. These techniques, very efficient in the instruction/education period of the futures engineers in mechanical domain, are exemplified with a design software dedicated for bolted joints, which have to transmit static, dynamic and thermal working loads.

Keywords:
conception, computer grafics, computer aided design, pre-stressed bolted connections

1. INTRODUCTION AND CONTEXT

Despite a variety of new joining techniques, nuts and bolts still play an important role for many industries.

One of the most important causes of bolted joint failure is incorrect prestress, though more attention is generally given to the torque value when tightening the nut. In spite of several well known measuring methods, prestress is still difficult to check. While the designer knows the forces on machine parts or flanges, he often does not account for losses through friction and material settling when parts are repaired.

On other hand, the most currently used methods of bolted joints design induce often important differences between the necessary and the effective characteristics of the final product. The different phases passed for a joint in order to satisfy the desired function will induce important drifts. These results, generally, from an insufficient knowledge of the bolted joint and of the effects of certain deviations on the reliability in service. In different phases of the implementation, the deviations arise from oversizing in the design phase, surface finish by manufacturing, tightening facilities by assembly, etc.

The ignorance of the repercussions of certain deviations on the quality of the product leads to the tendency of employing a safer, but too severe projecting procedure. If the quality of the products requires it, very close tolerances on the implemented controls will ensure the

reliability of the assembly by rejecting bad parts. In the case of high performance joints, these methods of manufacturing are severely penalized because of their lack of flexibility.

Calculation only applies by considering the loads acting upon a single fastener. When a joint comprises several fasteners, a mechanical analysis of the external loadings will have to be carried out beforehand, in order to define the resultant loads related to the calculated fastener (axial load, transverse load, bending moment).

The Cetim-Cobra calculation method applies to bolted joints which have to transmit static, dynamic and/or thermal working loads. It determines the optimal preload to fulfill the non-opening and/or non-sliding of the clamped parts. These joints necessarily use high duty fasteners (screws, bolts, studs or threaded rods) and a controlled tightening.

2. THE CASE STUDY. METHODS AND PROCEDURES

The suggested methods and procedures result from a complete calculation of the bolted joint. In the most complex case, the algorithms of the proposed software comprise different calculations and include multistandards databases (ISO, EN, BS, DIN, AFNOR, etc.) and wizards. These allow an easier data entry for the standard dimensions (as bolt, nut or washer) and the mechanical characteristics of materials.

Considering the initial data of the joint: geometry, mechanical and/or thermal loadings, material characteristics, the software determines the necessary data for the design and assembly, which would insure an optimal use of the joint. It checks that the bolt and clamped parts can sustain the tightening loads and can work static, dynamic and/or thermal loadings. The Cetim-Cobra calculation method comprises several essential modules such as the calculation of the fastener and clamped parts resilience (or stiffness) and the thread stripping behavior. Regarding the software functionalities for a bolted joint calculation, Cetim-Cobra can take up to 90 different parameters into account.

- Calculation parameters: The mechanical and/or thermal loadings; The geometrical and mechanical characteristics of the fastener (screw, bolt, stud, threaded rod or nut); The geometrical and mechanical characteristics of the clamped parts (washers included); The tightening conditions: tightening method, friction coefficients, preload limits.

- Calculation results: The resilience (or the stiffness) of the fastener and clamped parts; The dynamic stress in the thread of the fastener (to prevent fatigue failure); The minimum required preload ensuring the non-opening and/or non-sliding of the clamped parts in work, i.e. to prevent joint failure; The maximum allowable preload which takes into account the limit of all the assembled material characteristics; The maximum stress in the fastener; The minimum strength of the fastener, when the property class is not defined; The fastener elongation after tightening (to prevent loosening); The maximum stresses in the spring washers; The pressure at the joint faces (to prevent loosening); The minimum and recommended thread lengths of engagement in the case of a tapped part (to prevent thread stripping); The optimal tightening setting (torque, angle or tension) which takes into account the results above and a possibly prevailing torque.

- The facilities for the user are: In-line help with figures, integrated theoretical handbook and technical documentation, knowledgebase, external references; Evolutionary and standard databases: material characteristics, component dimensions (integrated manager); 5 wizards; Check of the data conformity before any calculation; Quick description of the parts by using basic sub-shapes; 3D or cross section view of the joint after modelling; Compressed volume or
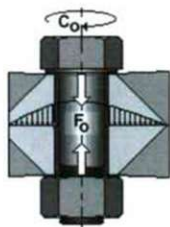
compressed area at the joint faces view after calculation; Result analysis; Calculation report printing in English or in French; Calculation report exportation in a word-processing software (via a RTF file).

Cetim-Cobra is in conformity with a linear model in the case of cylindrical clamped parts with a uniform cross section. The other geometrical cases are calculated by extrapolating what has been validated by finite elements analysis.
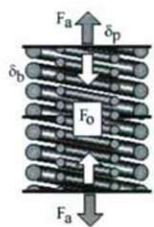
3. THE BASES OF THE CALCULATION IN *Cetim-Cobra* SOFTWARE

In a pre-stressed joint, [2], the preload F_o is an axial tensile stress in the bolt (Figure 1, 2, 3) whereas the parts are compressed.
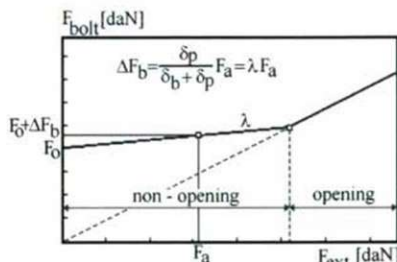

| Fig.1. | Fig. 2. | Fig. 3. Relationship between the load in the |
| Bolt axial tensile stress | Bolted joint calculation model | bolt and the load applied to the clamped parts |

In principle, the bolted joint is modeled using springs, in a rather simple way (Figure 2): the spring of resilience δ_b simulates the bolt, and the spring of resilience δ_p simulates the clamped parts. The joint is tightened with an initial preload F_o. A positive external load F_a increases the tension in the bolt of ΔF_b. This tension is only a fraction of F_a in the proportion: $\Delta F_b = \lambda\, F_a$. The behavior of this model, [2], is exemplified in Figure 3.

To prevent any cracking (at the fatigue resistance of a bolt for example) the designer will have to size the joint in order to remain in the non-opening area. Concerning the control of the tightening conditions, in practice the preload F_o will vary in a certain range, whatever the tightening method used, considering the tightening tool accuracy and manufacturing tolerances of the parts. Determining this range with precision is very important, as its minimum value must ensure that the parts remain in contact regardless of the working loads, and its maximum value must not exceed the mechanical characteristics of the materials in contact.

4. EXAMPLE OF A STUDIED JOINT

A typical example of an industrial application is the pre-stressed bolted joint - Prismatic flange, [2].

We consider such a bolted joint, with the configuration of the studied part of the connection presented in Fig. 4.

The joint configuration result is produced with the *CONFIGURATION* module, and displays the data previously entered in the *"New project file"* wizard.
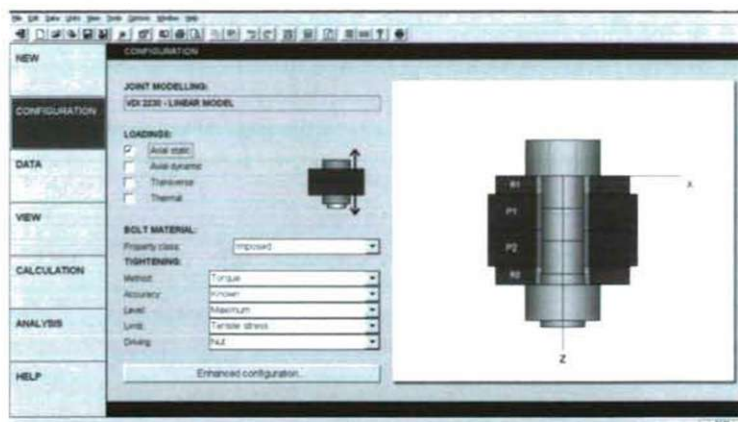
Figure. 4.: Pre-stressed bolted joint - Prismatic flange in the CONFIGURATION module

In order to create a project file in the CETIM-Cobra software, we must declare (and/or select from a predefined list) the following data: the calculation method (for example, if loadings are known, one can demand a complete calculation of the joint behavior in service); the fastener characteristics; the tightening components; the clamped parts (the parts compressed during the tightening); the external mechanical loadings.

Generally, the material design is automatically obtained when using a *Material database* either from the modulus of elasticity field, or the yield compressive strength field.

The material used for the joint parts are made of heat treated steel, with the following mechanical characteristics:
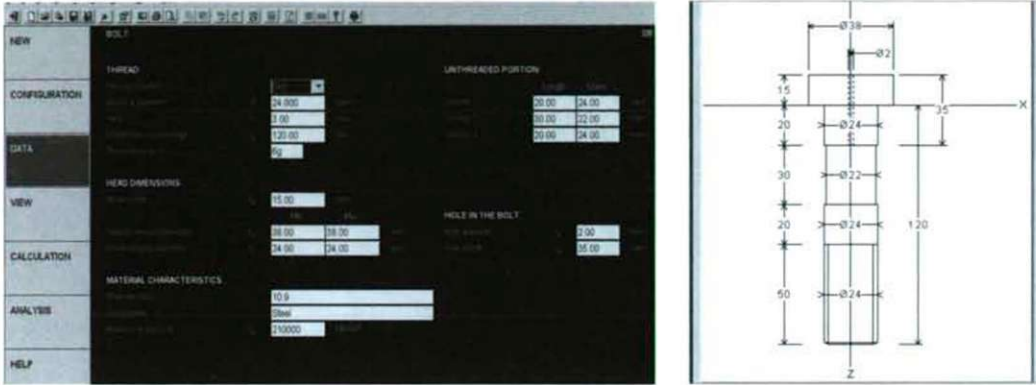
modulus of elasticity at 20°C, 210000N/mm²; yield compressive strength, 900 N/mm²; yield shear strength, 420N/mm².

In the *DATA* module, the input data pages are classified by considering the type of the following parameters: Loadings; Description of the fastener; Description of each part of the joint; Tightening conditions.

In the studied joint we have considered the following mechanical loadings: Maximum axial external force, $F_{a\ max}$ = 1000 N; Excentration x_F = 32.50mm; Loaded parts: Flange1 and Flage2; Load introduction factor, β=0.70.
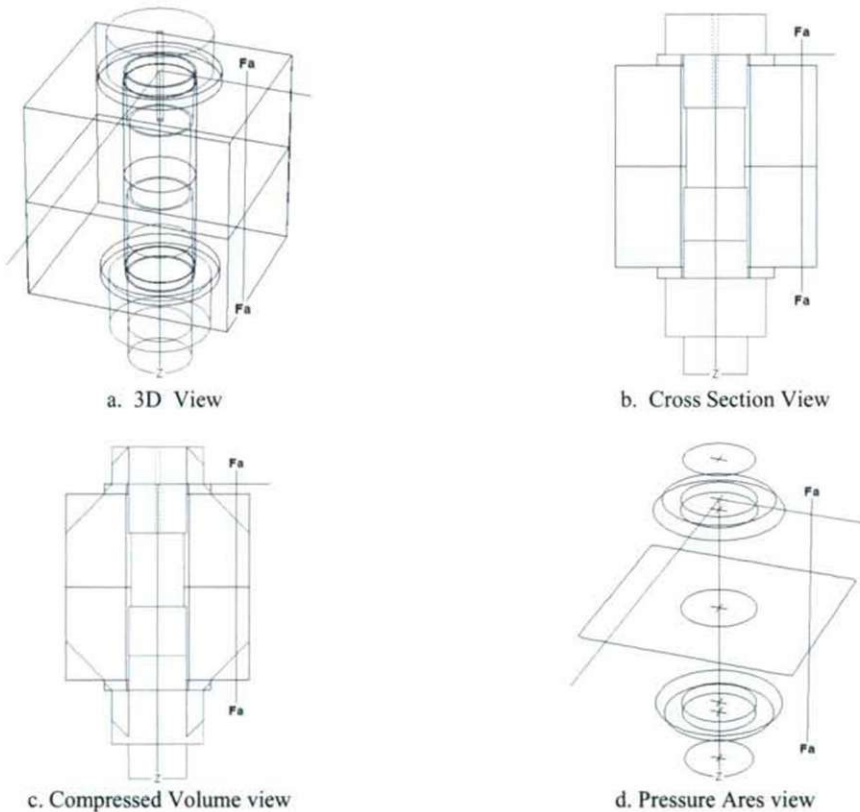
The constituent and the components parts of the joint, respectively Bolt, Washer 1, Washer 2, Flange 1, Flange 2, Nut, have been configured in the *DATA* module.

As example, the configuration of the bolt and the modelling of its components are illustrated in Figure 5.

Figure 5. Bolt configuration and modelling of its components in the DATA module

The modelling of the joint is displayed in the *VIEW* module. By click on the specific button, the following views options are available: *3DView, 2DCrossSection, Compressed Volume, Pressure Ares* (Figure 6a -Figure 6d).

a. 3D View

b. Cross Section View

c. Compressed Volume view

d. Pressure Ares view

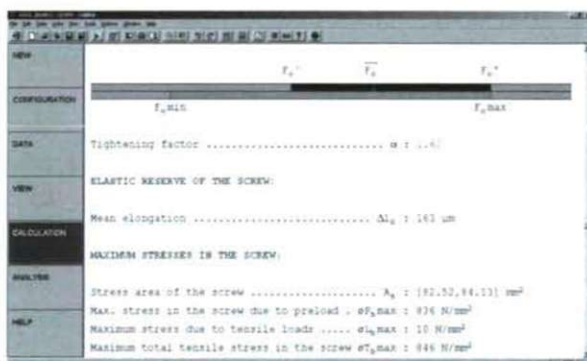*Figure.6. Modelling of the entire joint displayed in the VIEW module:*

a - 3D View; b - 2D Cross Section; c - Compressed Volume; d - Pressure Ares

This allows us to check if the relative parts positions, as well as the position of the parts in comparison with the axial external load F_a, respectively the position of the fastener inside the parts (incompatible diameters, emerging holes, etc.), are correct.
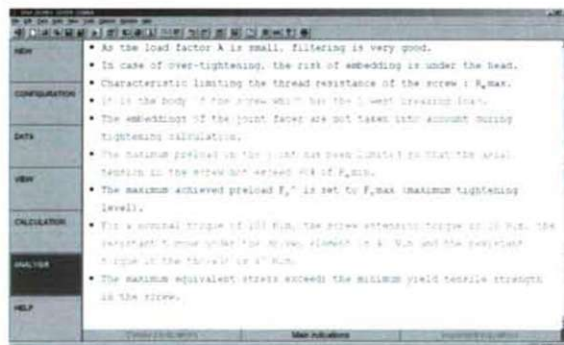
The calculation of the joint, preceded by a data check, is conducted in the *CALCULATION* module, Figure 7.

In case warnings, faults or errors are detected, a dialog box is automatically open and we can carry out a correction by an interactive "coming back", directly in the corresponding input page of the *DATA* module.

Figure 7. Results examples of the joint calculation

Finally, examination of results and *Results Analysis* are possible in the *ANALYSIS* module, Figure 8. This module notes resulting from the calculation, help to interpret the calculation report and displays options. Using the commands buttons *Detailed Indications, Main Indications* or *Important Indications*, the software attributes a color (red, green, blue or black) according to the importance of the message.

Figure. 8. Resulting messages in the ANALYSIS module

The final calculation report can be displayed on the screen or printed, with content from all of the active modules: the input data from CONFIGURATION and DATA modules; the views of

the joint, from the VIEW module; the results of pre-stressed bolted joint calculation (according to the checked options in the "Report layout" dialog box) from the CALCULATION module; the current analysis messages from the ANALYSIS module. This calculation report file can be exported in an .rtf file and afterwards loaded in an word-processing software.

An important facility of this software is the efficiently *context help*, respectively a theoretical handbook, technical documents, knowledge base, Pictures and a Video library. The described CETIM Cobra software can check dimensions of an existing joint, when working loadings must be modified and the design of a new joint is not possible.

5. DISCUSIONS, APPROACHES, APPLICATION AREA AND LIMITS

The Cetim-Cobra calculation method determines the optimal preload to fulfill the nonopening and/or non-sliding of the clamped parts. These joints necessarily use high duty fasteners and a controlled tightening.

When a joint comprises several fasteners, a mechanical analysis of the external loadings will have to be carried out beforehand, in order to define the resultant loads related to the calculated fastener: axial load, transverse load, bending moment.

Cetim-Cobra can only treat joints which have a continuous volume of material around the bolt, and this volume must be entirely compressed. The described design software tool Cetim-Cobra is available for the dimensioning of bolted assemblies with a controlled prestress. It allows prestress levels to be determined, for given loading conditions, and verifies the fatigue resistance of assemblies subjected to cyclic loading.

The geometry, materials and mechanical and thermal loadings are entered and the software calculates stresses and strengths (from a material database if required). The fatigue behaviour is then checked and partial safety factors are determined. The programme runs under Windows (English, French and German versions) and it includes graphical options for displaying the results.

The most frequent causes of failure of bolt connections are the following: Incorrect knowledge of actual occurrence and action of external forces; Additional bending stress in the bolt due to shape and position deviations of the bolts and nuts; Loss of pre-stressing caused by thermal elongation or plastic deformation of the bolt and connected parts; Spontaneous loosening due to shaking; Chemical or electrochemical attack, corrosion; Breaks of connection bolts exposed to variable loading.

6. CONCLUSION

The complexity of an optimized bolted joint calculation represents many work hours for a designer perfectly initiated with the specific calculation methods. In order to avoid long and expensive developments, the designer uses various "safety factors" involving an oversized joint designing. Even if it's obvious that this approach can't allow any cost-cutting, we have to point out that oversizing can sometimes decrease the mechanical resistance of the joint.

The large possibilities of a design and analysis software for pre-stressed bolted joints and the widespread of computer equipment in all branches of industry, [2], increases the possibility of using it in every phase of development or implementation of the joints.

Table 1.

Type of company	Phase of implementation	Typical use
Engineering	Design	Optimization
Mechanical manufacturing	Manufacturing	Processing control
Mechanical engineering	Assembly	Definition of the procedures
All types	Operating	Monitoring in service

For some safety systems, the calculation speed of the software allows a reduction of plant shut-downs.

Therefore, the integration of a computer aided design software in the concept process saves time, allows more exact calculations and deletion of some "safety factors" masking the lack of knowledge of the problem.

Once the complexity of the calculations is no longer a drawback, the designer will be able to consider several allowable configurations and to make a choice according to economic criteria. Integrating CAD's basic concepts, namely the use of a specifically design and analysis software (for example the Cetim Cobra software), in the instruction period of the futures engineers in the mechanical domain is a very efficient education technique.

REFERENCES

1. Cetim-Cobra, Logiciel de calcul des assemblages vissés et boulonnés. Centre technique des industries mécaniques, France.
2. CETIM© - Cobra Technical Manual, Update 29/09/2004, Version 4 for Windows
3. L. Champaneya, P.A. Boucardb, S. Guinard - Computational Strategy for the Analysis of Bolted Joints Taking Into Account Variability, Preprint submitted to Elsevier Science, August 2006
4. www.ferret.com.au/n/Know-the-nuts-and-bolts-of-prestressing-n686432
5. Theory of Rod Bolts and Other Prestressed Bolts www.eaa1000.av.org/technicl/rodbolts/rodbolts.htm
6. Bolt connection www.mitcalc.com/doc/boltcon/help/en/boltcon.htm
7. Mémento de visserie. Précontrainte dans une liaison vissée http://technocalcul.celeonet.fr/FR/precontrainte.html